Problem-solving culture in Commercial Transport Manufacturing

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Abstract

Financial success for a new airplane program depends on smooth progress over years of development, then rapid productivity improvements once a program goes into production.

In recent airplane programs, much attention has been paid to outsourcing, versus integrated design and manufacturing. However, the history of this industry shows that problem-solving culture and rapid productivity improvements are essential for profitability.

Research methodology

This study is based on interviews conducted over a period of years with industry executives, aerospace workers, union officials, academics, economists, journalists, financial analysts and industry observers. Demographic data were provided by Boeing under routine data requests as part of collective bargaining agreements. Foreign content for airplane models is reported to the Export-Import Bank.

The commercial transport industry may be regarded as mature, in the sense that the last major leap in design was introduction of jet engines over 50 years ago. Improvements since then have been incremental.[1]

Investors and airline customers see the jet transport as a commodity, rather than a breakthrough or disruptive product. On the other hand, the design and manufacture of the airliner is still performance-driven, requiring intense coordination to produce a new model profitably.

Comparison to other industries

Pressure to outsource is intense. Investors expect outsourcing to reduce financial risk, deliver market efficiencies and reduce cost.

Peter Cappelli gives two familiar examples of industries that involve complex products with high creative and technical content. Both outsource successfully as a matter of routine. One is the motion picture industry. The other is the high-tech industry in Silicon Valley.[2]

In Silicon Valley, the intense business environment creates highly effective social networks, with frequent face-to-face interactions at business and technical levels. Collaboration from one program to the next builds trust and confidence. These social networks manage the flow information relatively well.

Similarly, in the 40's and 50's, the motion picture industry transformed from the integrated studio model to a highly modularized model, where projects operate in highly specialized, geographically compact markets with rich supplier networks for technical, creative and financial resources. Social networks abound in this industry and information flows easily.

Test case for the aerospace industry

The 787 program is a useful study object for the aerospace industry to analyze the transition from integrated design and manufacture to a more modularized global supplier business model.

The trend to greater outsourcing is illustrated in Figure 1, which shows increasing levels of foreign content with each new Boeing airplane model.

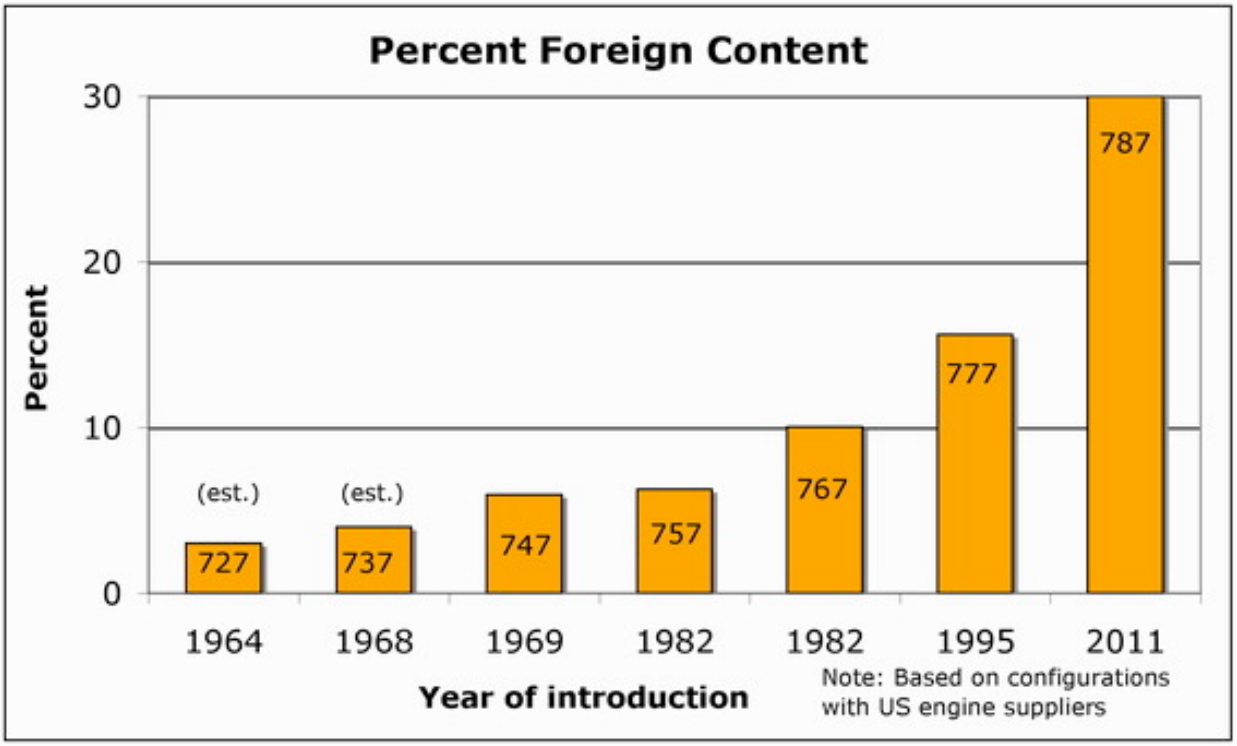

Figure 1. Increasing foreign content of commercial airplanes

The 787 program was launched in April 2004. About 30% of the 787 is outsourced to foreign suppliers. The total level of outsourcing, including domestic suppliers, reportedly comes to 70%.[3]

One way to choose which activities to outsource is to determine the relative value of each activity, retaining those that can command high premiums, and outsourcing those activities that are more commodity-like.

This type of analysis is a good first step, but it ignores task interdependencies and assumes a rich, capable, reliable supplier base.

Prior to launching the 787 in April 2004, Boeing executives concluded that the firm's high-value activities were product development, project management and system integration. Other parts of the business were seen as more commodity-like in nature, and could be transferred to the global supplier network.

In 2001, a paper presented at Boeing's annual Technical Excellence Symposium argued that a heavily outsourced business model encourages sub-optimization and actually increases program risk, rather than decreasing it.[4] The study observed that, over time, suppliers were likely to retain the bulk of any productivity improvements. Developmental programs inevitably

encounter problems and the initial production units are built at very high cost. The production process must drive down the learning curve rapidly, to achieve profitability. As problems arise over the course of development, the prime contractor is obligated to absorb additional costs of resolving the problems.

This argument was made retrospectively, based on experience with commercial airplane programs at McDonnell Douglas.

In general, candidate activities for outsourcing share these characteristics:
- A rich supplier network
- Standardized interfaces
- Mature products, well out on their learning curves
- Stable manufacturing processes
- Low margins

Characteristics of aerospace industry that argue against outsourcing are:
- Products are complex and heavily-engineered.
- Extensive coordination and communication are required,
- Very large capital investment is required, years in advance of any revenue.
- Programs are vulnerable to sub-optimization.
- Unit costs are very high.
- The supplier base is thin and geographically dispersed.
- Production and operational lifetimes can reach decades.
- Steep learning curves are assumed for profitability
- High standards for safety, reliability and performance must be met from the first delivery.

By comparison, sophisticated electronic goods, such as cell phones, hard drives and flat screen televisions can endure repeated failure of individual items or entire product lines with relatively little market consequence. In the motion picture industry, a high percentage of products flop each year.

Given the very high initial investment for transport programs, manufacturers must reach high production rates and realize economies of scale quickly.

As a new model enters service, dispatch reliability is tracked. The trend in dispatch reliability will serve as a figure of merit that helps define the new model’s reputation.

Problem-solving culture
Every large aerospace program is known for its problem-solving culture.

<u>747 Program</u>
The 747 development program established a problem-solving strategy used

often at Boeing. In the words of a former GE executive, "Whenever Boeing had a production problem, they would throw people at it. Boeing is a company that will spend money to solve a problem."[5]

757 and 767 Programs

The 757 and 767 development programs ran concurrently in the late 1970's and early 1980's. The programs introduced the idea of Extended-range Twin-engine Operational Performance Standards or ETOPS, which allowed those airplanes to fly more profitable direct routes over water.

The 757 and 767 design teams coordinated routinely on major and minor decisions, formally and informally. The frequent interactions led to strong social networks based on technical interaction, status meetings, and tacit interactions. Project leaders reinforced this behavior consistently.

The two development teams were resourceful enough to take on additional program risk during the development phase, by incorporating elements of the 757 flight deck design into the 767, to take advantage of aerodynamic efficiencies revealed in early testing.

Boeing introduced its use of digital design tools, with a pilot program for the 767 engine pylons. It also established the shift to global production, adding the Italian firm Aeritalia and a consortium of Japanese companies as risk-sharing partners.

777 Program

The 777 program's problem-solving culture was distinctive, characterized by its slogan, "Working Together."

Continuing their role in the 767 program, the Japanese consortium manufactured most of the fuselage for the 777. Representatives from major suppliers and customers were co-located in the workplace with the design teams. About 30 teams worked at a high level of integration, and about 230 design-build teams worked at a more detailed level.[6]

Launch customers wanted their aircraft to enter service with very high dispatch reliability, and immediate ETOPS certification. This put a correspondingly high priority on safety, reliable designs, and stable processes. The 777 was the first Boeing commercial airplane with fly by wire controls. The 777 design was fully digital. The transition to digital design was very expensive, and early workstations were notoriously slow. The 777 introduced use of composite materials for primary structure in the vertical tail and horizontal stabilizers.

Program leadership reinforced the expectation that problems and stakeholder interests should be addressed as far upstream in the process as

possible. This meant that contending interests could be balanced early, at relatively low cost. Participants in design teams built trust and confidence, which provided an ongoing basis for resolving problems promptly.

Even so, program costs ran roughly 50% beyond the original budget. Press accounts reported deep concern among investors, who objected to the overruns.[7]

Continuous Quality Improvement

In the mid-90's, Boeing reached a peak of problem solving culture with a series of initiatives known collectively as Continuous Quality Improvement, or CQI. CQI guided process improvements in design, manufacturing, support services and office processes. Small workgroups had authority to analyze their workflow, interact with other organizations upstream and downstream of their work area, look for efficiencies, and challenge existing methods. Employees learned statistical methods, and made decisions based on data collected in the workplace by coworkers.[8]

By mid-summer of 1997, the President of Boeing Commercial Airplanes concluded that large airplanes were “approaching theoretical perfection,” in terms of physics, aerodynamics, and overall performance. In the new global supplier business model, responsibility for process improvements and innovations would shift to suppliers. This implicitly recognized that commercial transport production was mature and the products were becoming more commodity-like.

787 Program

Historically, suppliers worked under an arrangement known as "build to print," meaning that Boeing designers would release detailed drawings with supplemental instructions to suppliers.

Starting with the 787, suppliers would work to "performance specifications." In a performance specification, project managers explained what the object or component would do, and the supplier would design and build it. For instance, Boeing might specify the aerodynamic shape of wing, and what loads to anticipate. The Japanese suppliers would decide how to make the spars, how many ribs were needed, where to place the ribs, how the skin attached to the ribs, and what materials and manufacturing processes to use. The supplier would also incorporate many of the systems and components into the wing sections, so major assemblies would arrive for final assembly, already "stuffed."

While this was the principle, in practice Boeing engineers teamed with Mitsubishi to manufacture a demonstration article of a full scale, two thirds-span wing at a facility in Seattle, very early in program development. Boeing also made demonstration fuselage sections for other global suppliers.

In this new business model, suppliers own the design. Suppliers would not necessarily share details with Boeing regarding the stress models, analytical details, electronic designs, testing procedures and software.

In past programs, activity was charted in detailed schedules, and tracked in frequent status meetings. In the 787 program, tight coordination was replaced with collaboration. Under contractual arrangements with suppliers, Boeing program managers and system integrators had limited oversight of work. In many cases, Boeing might not be aware of a problem until the supplier missed their delivery date.

Chief Engineers

Chief Engineer was a key position in airplane programs, prior to the 787. The 787 program had no positions for Chief Engineers, *per se*.

A Chief Engineer has ultimate responsibility for resolving technical problems and conflicts between different stakeholders. For instance, in the 777 program, the design-build teams would work to resolve issues. If a problem exceeded the authority of the design-build team, then problem-solving responsibility fell to those Chief Engineers whose functional areas were affected.

Chief Engineers held technical responsibility to analyze problems, evaluate potential solutions, reallocate resources and determine which stakeholders would sacrifice their individual interests to reach a solution that was best for the program overall. That is, Chief Engineers are responsible for decisions and behavior that were globally optimal.

On the other hand, stakeholders in a modularized business model have a relatively weak obligation to the project as a whole. A supplier may object to a solution that is not in its immediate interest. For example, one 787 supplier, Vought, sold its stake in two large facilities after years of delays and unforeseen costs. Vought acted to protect its own financial interests.

Comparison of problem-solving cultures in 777 and 787 programs

The 777 and 787 were both heavily-outsourced programs, but their cultural messages differed fundamentally.

The 777 brought major stakeholders into decision-making, balancing interests as part of the problem-solving culture of the program. Project leaders expected information about problems to move upward quickly from the workplace to program leaders. External stakeholders were included in the team structure, which built on-going social and technical relationships and reservoirs of trust and confidence. This made it more likely that problems could be solved quickly and stakeholders would accept decisions

that optimized the program overall.

Engineers in successful large-scale integrated projects will routinely sacrifice personal interests for the overall good of the product or the program. Engineers working for a supplier are less inclined to sacrifice their employer's interests.

In the 777’s active problem-solving culture, frequent status meetings and detailed coordination drew out information as early as possible at the workplace level. As problems were revealed, coordination and solutions were managed within the routine flow of work.

In contrast, the 787 program was structured to shift decision-making authority out into the supplier network. Schedules were tracked at a relatively high level, leaving suppliers responsible for the details in their own work packages. While engineers and managers may have had knowledge or indications of problems, the communication of problems upward to program leaders was very weak.

Significantly, the 787 program culture discouraged awareness of bad news in two ways. First, those bringing bad news would be criticized for not being "team players." Once workers in one area became aware of "shooting the messenger," that example would impress workers in other areas, becoming a disincentive for workers to risk criticism by raising problems.

Perhaps a more profound disincentive was that the 787 program had no real mechanism for resolving problems quickly and decisively. A common experience was paralysis and indecision, often expressed as "no one can make a decision." [9]

In this decentralized business model, Boeing had no authority to contradict the supplier's approach or intervene in the supplier's work. Groups were separated by distance, language, time zone, and corporate boundaries. These all became obstacles to communication.[10]

Astute engineers and managers could determine quickly that they had much to lose, and little to gain by raising problems to program leaders. At some point, a problem would become very serious. Not until then, would it be possible to mobilize resources to deal with it.

During 2008, a flood of production problems in the 787 program had mounted to the point where significant resources were finally mobilized to resolve production problems. Workers were co-located on the factory floor, in hundreds of desks and workstations around the airplanes, where they remained for months. Additional engineering groups are located in office towers adjacent to the assembly line.

Figure 2. Final assembly for 787, showing some of the desks and workstations on the factory floor near the airplane. Photo credit: Mike Siegel / Seattle Times.

Representatives of the suppliers were integrated into the recovery effort. While solutions were being worked out on the factory floor, decisions were coordinated back to the suppliers, and applied to work in progress at the suppliers' facilities. In a sense, this recreated the design-build teams of the 777 program, at least in function, if not in organizational design.

Significantly, the underlying business infrastructure remained under control of the suppliers. Under this split authority, each change was treated as an exception to normal processes and added significantly to the cost and effort to complete development.

Learning Curve

Learning curves are especially important in aerospace, where initial development can cost billions of dollars and revenue doesn't begin for several years. Ultimately, return on investment depends on a large backlog of orders, rapid ramp-up to full production rate, capturing economies of scale, and a strong revenue stream once deliveries start.

Typically, the first few units are very expensive, then cost per unit drops

rapidly. Improvements come in many small steps, from many activities distributed throughout the manufacturing process.

Progress down the learning curve can be disrupted by rate increases, supplier shortfalls, model changes, and skill dilution in the workforce. Newly hired workers may take 3 to 5 years to achieve full productivity. This individual learning applies to both hourly workers and engineering staff.

Significantly, productivity improvements don't "just happen." Process improvements come from an organized effort that encourages individual initiative on the part of hourly and salaried workers, and provides them with the resources and authority to make changes.

A common figure of merit for the learning curve is to say that each doubling of production lowers cost by 0.85.[11] That is, the 10th airplane would cost 0.85 as much as the 5th airplane, and so on.

Figure 3 shows a simple projection, with three different learning rates, 0.83, 0.85 and 0.87 per doubling of production. A program reaches a "break even" point when the program position goes from negative to positive.

If the learning varies slightly from .85 per doubling of production, the difference in program position can be billions of dollars.

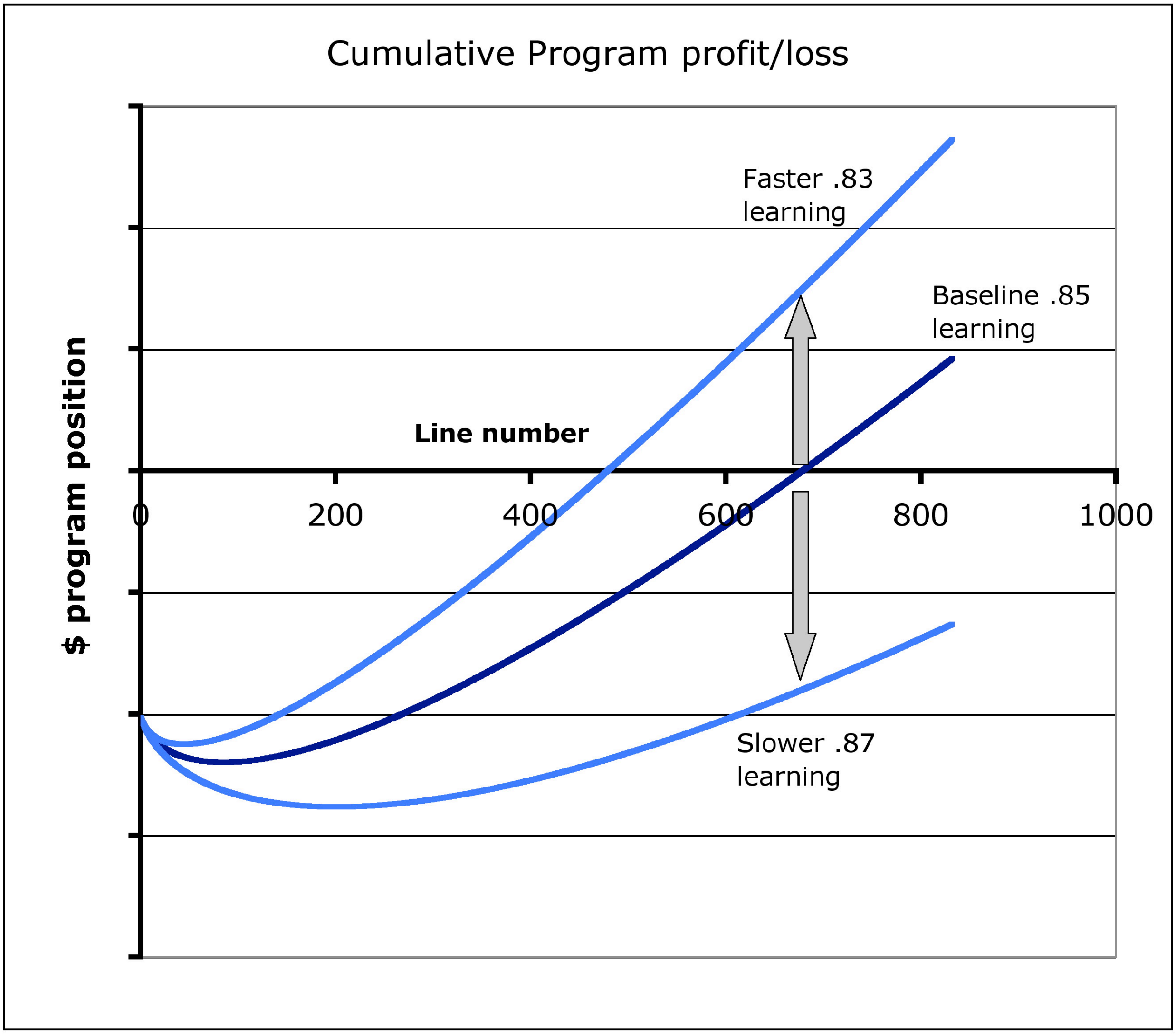

Figure 3. Simplified model of program position with three rates of learning.

787 learning curve
The 787 development costs are reportedly $12-18 billion over budget.[12]

Many airplane sales contracts provide penalties for late deliveries. One estimate puts 787 program penalties, as figured in 2009, at $5 billion.[13]

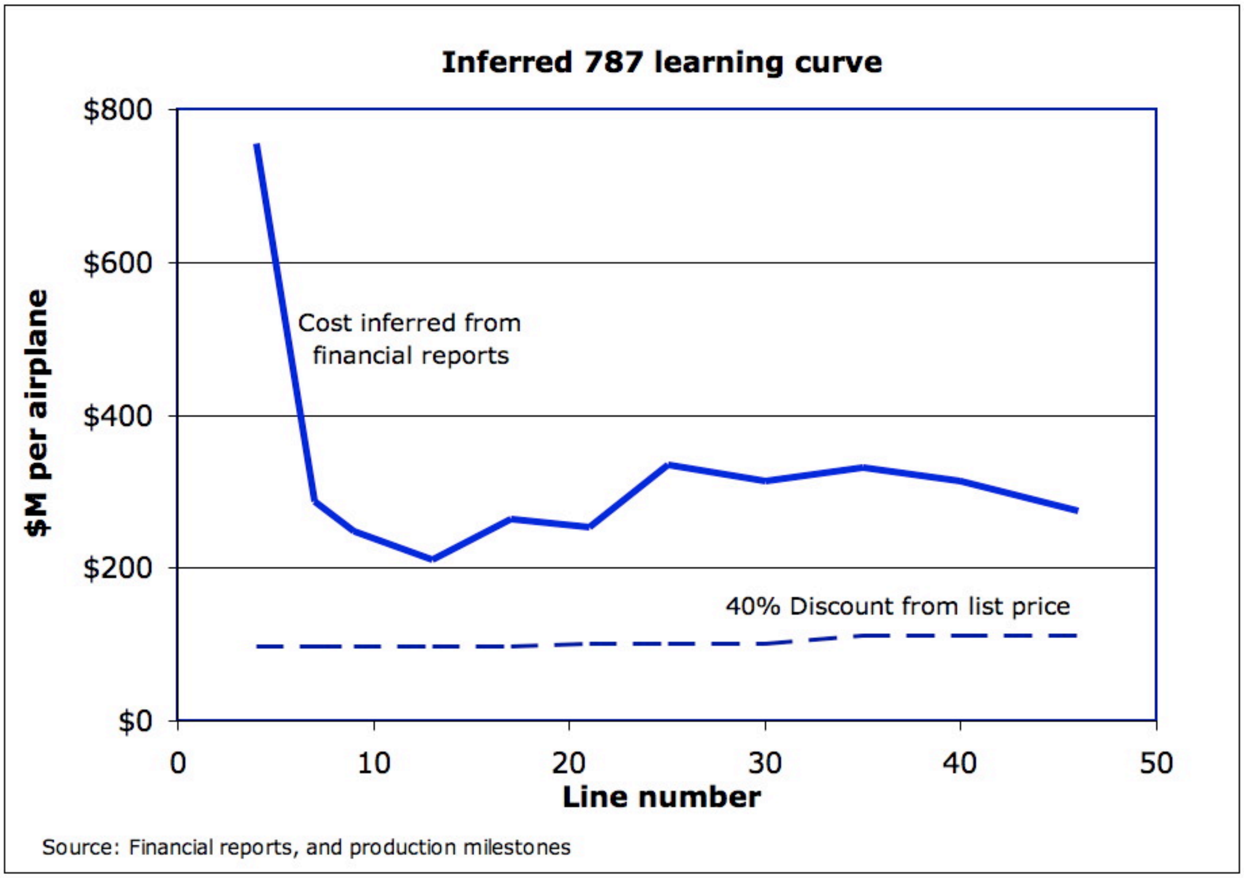

Figure 4. Inferred cost curve for 787 airplane, showing cost and figure of merit for revenue per unit.

Financial filings break out 787 inventory costs by quarter and production progress can be tracked in public statements about units as they enter final assembly. Unit costs are inferred from inventory costs in the quarter divided by airplanes produced in the quarter. For the 787, a discount of about 40% from list price is considered a fair estimate of revenue per unit.[14]

In the specific case of the 787, several obstacles hold back productivity improvements.

The 787 makes extensive use of light-weight composite materials. Composite materials and tooling are more expensive than metal, and the associated manufacturing processes are more rigid, so potential cost reduction in the 787 program may be lower than earlier programs.

Most of the productivity gains will occur in the supplier network, where the bulk of the work is performed. To the extent they can, suppliers will sub-optimize around their own business interests. Production rate is planned to increase rapidly from 2 airplanes per month to 10 per month. The supplier network is stressed by years of delays, and production was halted in early

2011 for over a month to sort out supplier delivery problems. To meet full rate, suppliers will need to invest in new facilities and equipment. The bulge of additional workers will take years to reach full productivity. Boeing will try to extract cost reductions from suppliers. However, suppliers now have considerable bargaining power, and the actual gains to the program are likely to be less than anticipated early in the project.

In October 2009, Boeing announced a second production line in South Carolina, with a largely inexperienced workforce, and its own local supplier base. Final assembly at the new site began in mid-2011. Bringing that facility up to full productivity will stretch any learning curves.

A point of concern for future productivity improvement is the demographic profile of the existing workers. Figures 5 and 6 show aging trends over the last 20 years, for two populations in the workforce. Figure 5 corresponds to engineers and scientists. Figure 6 applies to technical workers, including drafters, planners, industrial engineers, laboratory technicians and inspectors.

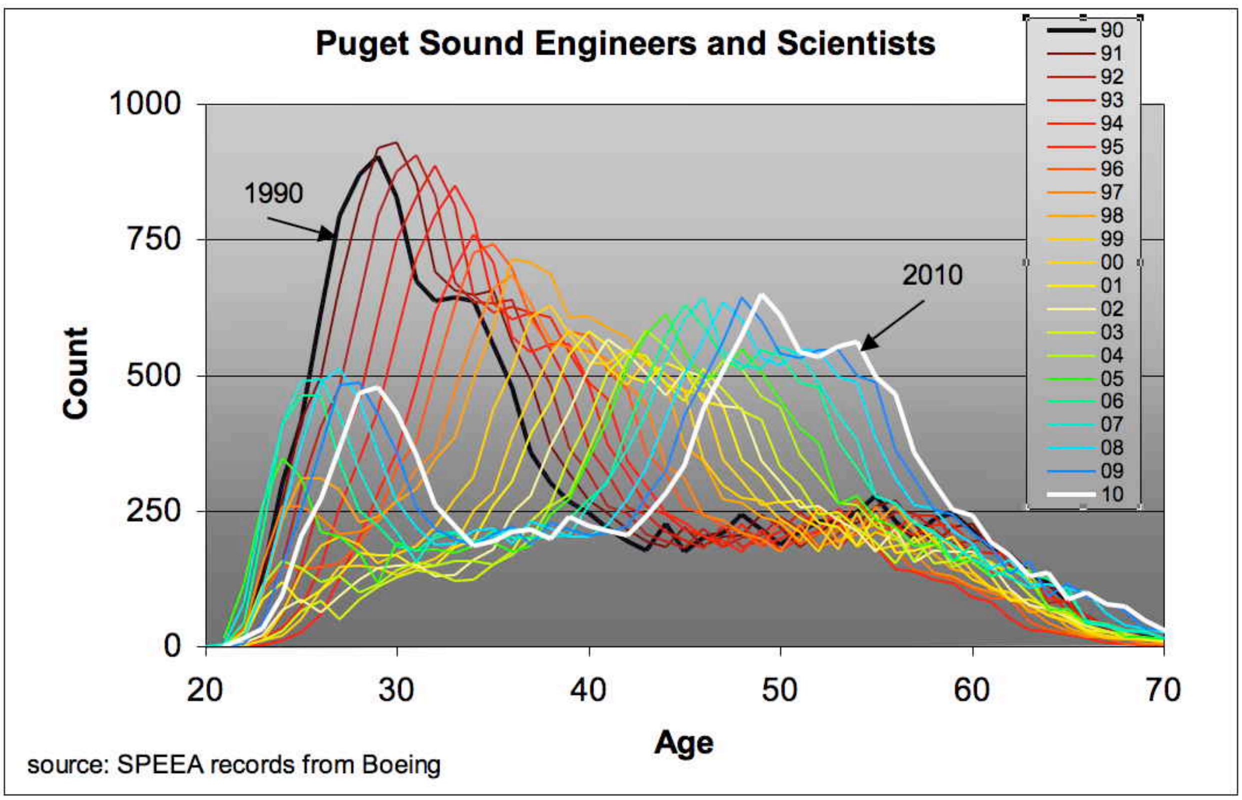

Figure 5. Demographic profiles for engineers and scientists from 1990 to 2010.

Weak hiring and repeated layoffs over the last two decades resulted in a

split distribution. The age profile for hourly workers is also split, with a large cohort of recently hired workers.

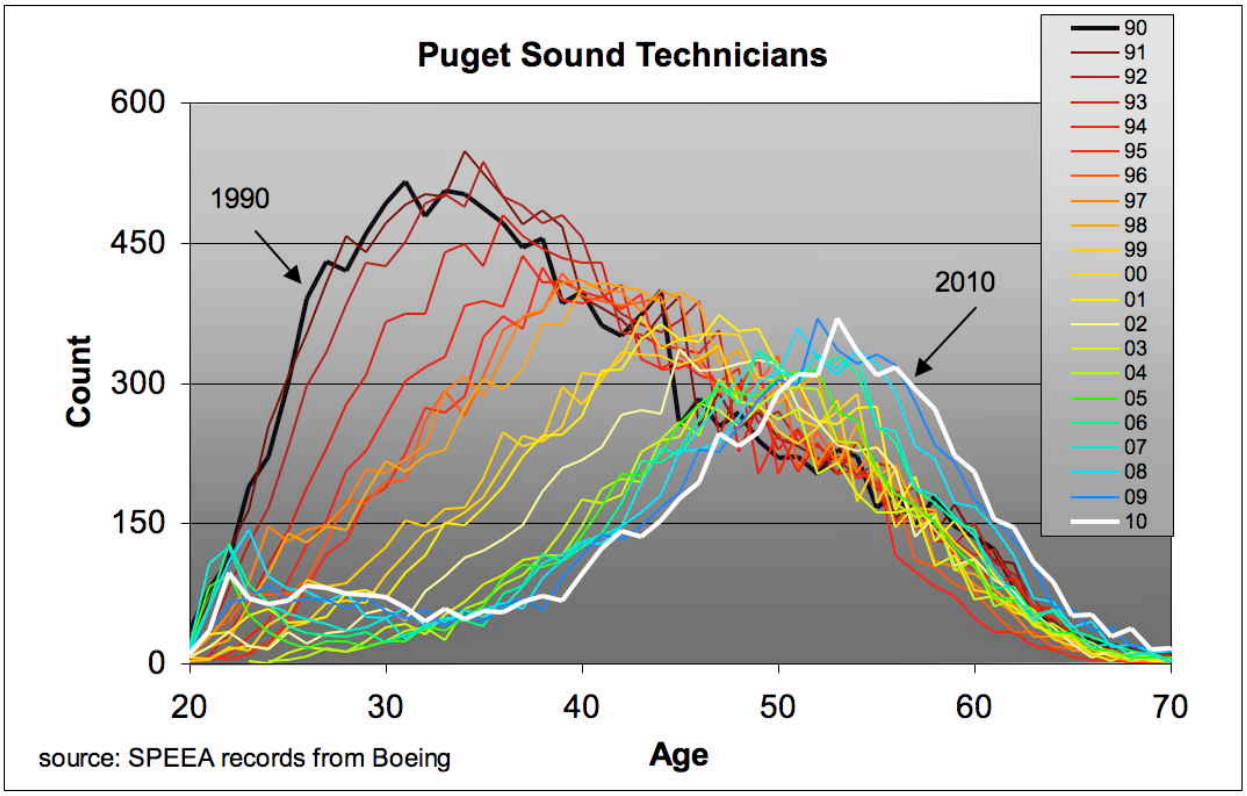

Figure 6. Demographic profiles for technical workers from 1990 to 20010.

Perhaps more troubling, pending retirements will also deplete the population of managers and project leaders who have valuable experience from previous successful programs. These managers typically come from the ranks of mid-career engineers and production workers, who are largely missing from the current demographic profiles. The next generation of workplace leaders has had limited exposure to a strong problem-solving culture.

This offers another point of comparison to other industries. Cappelli observed that firms in Silicon Valley experience labor turnover rates as high as 30% per year. In that industry, high labor turnover helps mediate flow of ideas among many small firms engaged in relatively small projects with short product cycles and high rates of innovation. Cappelli cautions that companies managing long-term projects would be pulled apart by high labor turnover.[15]

Conclusion

The 787 airplane program differs from earlier programs in terms of program management and its approach to problem-solving.

Historically, Boeing's characteristic problem-solving skills included making reasonable technical judgments, reaching agreement with key stakeholders, and reallocating resources to keep development programs on schedule. In simple terms, this often meant reassigning hundreds of workers and committing the corresponding levels of funding for tooling, materials, design changes, and facilities. This was managed in a largely integrated design and manufacturing work environment, including co-located engineers from global suppliers. Information flowed relatively easily, both laterally between organizations, and upward to program leaders from offices and shop floors.

The 777 program demonstrated that effective problem-solving behavior is possible, even with a heavily outsourced business model.

Chief Engineers retained authority to analyze problems, evaluate proposed solutions, modify program goals if necessary, distribute sacrifice, and reallocate resources among different stakeholders. Relationships that developed in team activities served to build a reservoir of trust and confidence.

For a variety of reasons, costs for the 777 program exceeded initial budgets by as much as 50%. However, the program met performance and delivery commitments; the 777 was ETOPS-ready for the first delivery; it had a very high dispatch reliability at entry into service; and it was very popular with airlines and passengers.

In contrast, the business model on the 787 program explicitly excluded coordination costs, relying instead on contractual relationships.[16] Suppliers often delegated authority for design and manufacturing to lower-tier contractors. Boeing in-house system integrators retained relatively limited authority.

Employees were discouraged from raising issues, either by the prevailing cultural message to be team players or through realization that they would be unable to resolve issues until problems reached very high levels of urgency.

The 787 program has suffered unprecedented delays, costs overruns, and technical shortcomings, which have damaged the company's reputation with airline customers, investors and the public.

As problems accumulated, project leaders returned to the historic norm, asserting *de facto* control at a technical level, reassigning hundreds of

workers, reconstructing an integrated co-located work environment, and committing significant financial resources.

Going forward, 787 program faces two significant challenges. First, production rate must increase from the current 2 airplanes per month to full-scale production rate of 10 per month. Simultaneously, productivity must improve to levels consistent with profitability. The target production cost is particularly low, since sales prices for the first 800 airplanes were negotiated years ago under very favorable assumptions.

Second, as older workers retire, the next generation of experienced workers with detailed knowledge of systems and structures will reside in the supplier network. Knowledge transfer on large programs is sometimes compared to walking, in the sense that walking is the process of always falling down, but you place one foot in front of the other.

Executives are speaking openly about lessons learned from previous programs. The next test for this industry will be the 737-MAX, a recently authorized derivative featuring new engines and minor structural changes. The choice of business model and the program cultures on this and subsequent projects will determine whether the US commercial transport industry recovers from its stumble and continues walking forward.

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